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Further dispersion of the invasive alien species *Corbicula fluminea* (O. F. Müller, 1774) in the Oder River

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Abstract – *Corbicula fluminea* is recognised as being one of the worst alien species in Europe and one of the world's most widespread non-indigenous species in freshwater ecosystems. In Poland, it was detected in a heated water channel of the Lower Oder Power Station near Szczecin for the first time in 2003. In the following years, it continued its spread in the Oder River and the Vistula River. Our study uncovered new findings of *C. fluminea* in the Upper Oder River, which are its southernmost localities in the Oder River. Its record in the Gliwice Canal indicates that this may be a new dispersion route to the east for this species.

Keywords: non-native species / *Corbicula fluminea* / Oder River

Résumé – Poursuite de la dispersion de l'espèce exotique envahissante Corbicula fluminea (O. F. Müller, 1774) dans l'Oder. *Corbicula fluminea* est reconnue comme étant l'une des pires espèces exotiques en Europe et l'une des espèces non indigènes les plus répandues dans les écosystèmes d'eau douce. En Pologne, elle a été détectée pour la première fois en 2003 dans un canal d'eau réchauffée de la centrale électrique de Lower Oder près de Szczecin. Dans les années qui ont suivi, elle a poursuivi sa propagation dans l'Oder et la Vistule. Notre étude a permis de découvrir de nouvelles observations de *C. fluminea* dans le cours supérieur de l'Oder, qui sont ses localités les plus au sud dans l'Oder. Son signalement dans le canal de Gliwice indique qu'il pourrait s'agir d'une nouvelle voie de dispersion vers l'est pour cette espèce.

Mots clés : espèce non indigène / *Corbicula fluminea* / rivière Oder

The Oder River is the sixth largest river in Europe. Its estuary is considered to be one of the most exposed environments for the introduction of alien species in the Baltic Sea catchment. As the main harbour, it plays an important role in both marine and inland shipping and is regarded as a significant gateway for the dispersal of non-indigenous species (Gruszka, 1999; Bij de Vaate *et al.*, 2002; Galil *et al.*, 2008; Gruszka and Woźniczka, 2008; Leuven *et al.*, 2009; Gruszka *et al.*, 2013; Pabis *et al.*, 2017). The number of alien macroinvertebrate species in the Oder River is still growing. By the 20th century, 16 non-indigenous species had been identified in the Oder estuary, among them were three mollusc species (*Potamopyrgus antipodarum, Dreissena polymorpha* and *Mya arenaria*) (Gruszka, 1999). Since then, 13 new alien species have been recorded in the lower and the middle courses of the Oder River including seven mollusc species – *Lithoglyphus naticoides* (Bij de Vaate *et al.*, 2002; Piechocki and Szlauer-Łukaszewska, 2013), *Ferrissia fragilis, Menetus dilatatus, Physa acuta* (Piechocki and Szlauer-Łukaszewska, 2013), *Corbicula fluminalis* (Łabęcka *et al.*, 2005; Piechocki and Szlauer-Łukaszewska, 2013), *Corbicula fluminea* (Domagała *et al.*, 2004) and *Dreissena rostriformis bugensis* (Woźniczka *et al.*, 2016).

Mollusca are one of the most invasive animals in freshwater ecosystems and can pose a serious threat to native species (Francis and Chadwick, 2012; Lorencová *et al.*, 2015). The Asian clam *Corbicula fluminea* (O. F. Müller, 1774) is a great example of this. The sexual populations of this species are restricted to the native Asian areas, but the androgenetic lineages are widely distributed in America and Europe (Pigneur *et al.*, 2014). *C. fluminea* is recognized as one of the worst alien species in Europe (Nentwig *et al.*, 2018) and one of the world's most widespread non-indigenous species in freshwater ecosystems (Hakenkamp and Palmer, 1999).

Many molluscs have proven to be very successful invaders. *C. fluminea* is one of the species that is greatly extending its distribution range. In less than 100 years, it has invaded all of the continents, except Antarctica (Crespo *et al.*, 2015). Since 2003, it has been spreading in the Oder and the Vistula Rivers; therefore, it is probable that it may also inhabit

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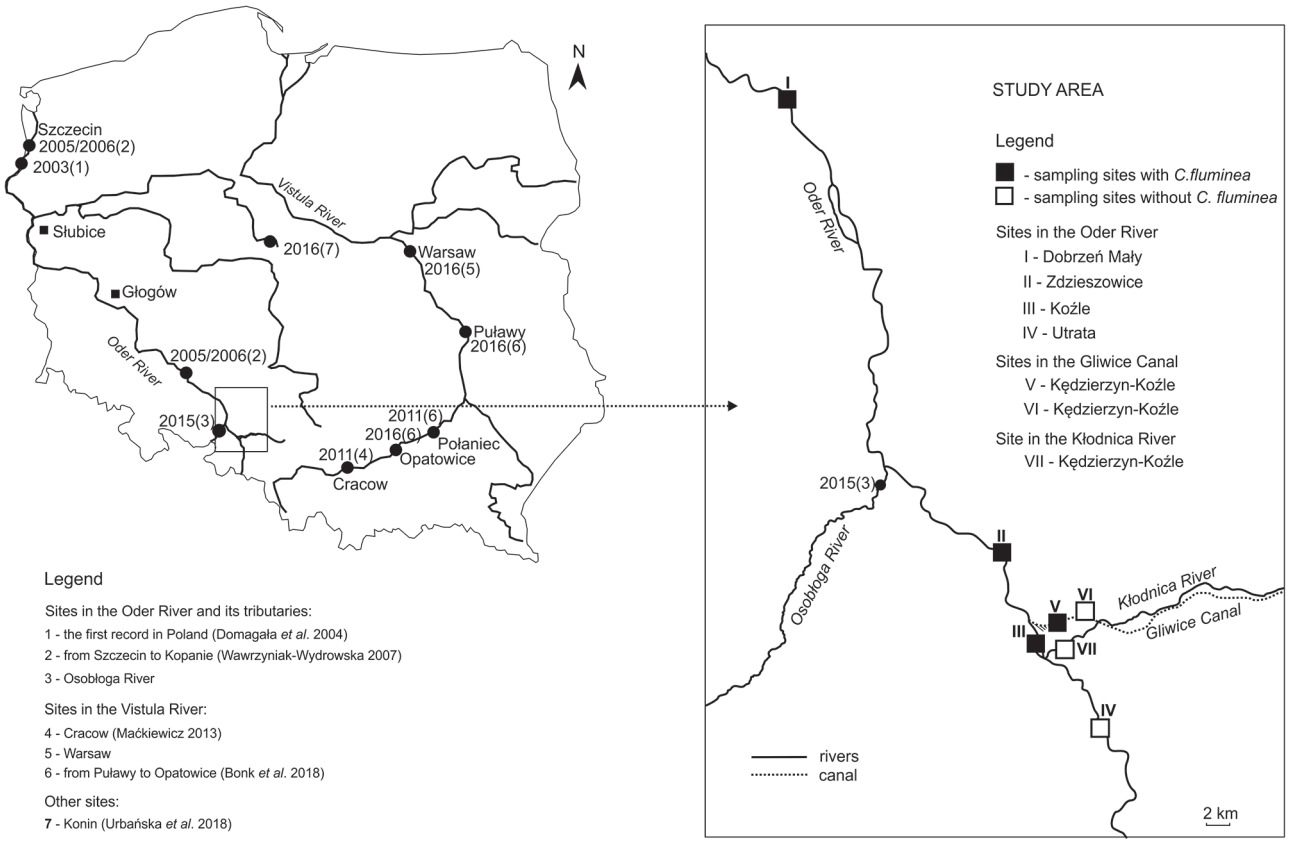

Fig. 1. Distribution of Corbicula fluminea in Poland.

other large rivers in Poland. The passive dispersal of *C. fluminea* is widely known to be predominantly attributed to human activity (deliberate or accidental), *e.g.*, ballast water transport, use as bait, use as a food resource, releases by aquarium hobbyists, and tourist curiosity. Pediveligers or juveniles can also be dispersed in a natural way, *i.e.* fluvial or tidal currents or transported on mobile animals such as birds and mammals (Crespo *et al.*, 2015; Coughlan *et al.*, 2017). Fish also may be an alternative possibility for its passive dispersal (Gatlin *et al.*, 2013).

In the Oder River, *C. fluminea* was detected for the first time in a heated water channel of the Lower Oder Power Station near Szczecin in 2003 (Domagała *et al.*, 2004). Another species from this genus, *i.e. Corbicula fluminalis* (O. F. Műller, 1774), was collected from this site one year later (Łabęcka *et al.*, 2005). Over the next several years, *C. fluminea* continued its spread in the lower and middle courses of the Oder River. It was found at six sampling sites from Zollbrücke to Ratzdorf in Germany (Müller *et al.*, 2007) and at 14 localities on the stretch of the river from Szczecin to Kopanie in Poland (Wawrzyniak-Wydrowska, 2007). In the following years, Piechocki and Szlauer-Łukaszewska (2013) identified further records of *C. fluminea* at 11 sites in the middle course of the Oder River (on the section from Słubice to Głogów). Wilke (2007) also reported *C. fluminea* in the Hohensaaten-Friedrichsthal Channel, which links the end section of the Oder-Havel Canal with the Western Oder. In 2015, Asian clams were found at the mouth of the Osobłoga River, which is the left bank tributary of the Upper Oder River; however, they were mistakenly identified as *Sphaerium rivicola*. In 2011, live specimens of *C. fluminea* were first recorded in the Vistula River in Cracow, Poland (Maćkiewicz, 2013). It is probable that it has been present at this site since 2008 and got there due to the engineering works that were carried out in the river. In 2016, the Asian clam was collected in the Vistula River in Warsaw and, few months later, from three localities above Warsaw. Its occurrence in the Vistula River (27 findings on the stretch from Puławy to Opatowice) was also recorded in 2011–2016 (Bonk *et al.*, 2018). The largest population and the largest individuals were noted at the outlet of a channel that collects heated water from the Połaniec Power Station as well as adjacent parts of the river (Bonk *et al.*, 2018). In 2016, a new population of *C. fluminea* was recorded in the Warta-Gopło Channel in Konin, which is a part of a power plant lake cooling system (Central Poland) (Urbańska *et al.*, 2018) (Fig. 1).

The expansion of *C. fluminea* has resulted in the continued increase in the number of habitats that have been colonised in the Vistula and Oder Rivers. Our study was carried out in the Upper Oder River (from Dobrzeń Mały to Utrata) in the Gliwice Canal, which links the upper course of the Oder River to the city of Gliwice in the Upper Silesian Industrial Region and in the lower course of the Kłodnica River (the right tributary of the Upper Oder River) from 2016 to 2017. Four sampling sites were situated in the Upper Oder River (along a 70 km stretch of the river), two in the initial stretch of the Gliwice Canal and one in the lower course of the Kłodnica River (Fig. 1). Samples of benthic macroinvertebrates were

Table 1. Physio-chemical properties of water and type of substrates at the sampling sites.

	Oder River				Gliwice Canal		Kłodnica River
	I	II	III	IV	V	VI	VII
Parameter	50°44.827'N 17°51.396'E	50°24.708'N 18°06.435'E	50°20.187'N 18°09.124'E	50°16.679'N 18°12.812'E	50°21.521'N 18°09.615'E	50°36.318'N 18°21.046'E	50°20.257'N 18°10.861'E
Temperature (°C)	12.8	18.3	19.4	18.1	24.5	25.4	21.9
Oxygen (mg O_2 dm^{-3})	9.10	5.28	10.9	9.45	10.41	4.26	7.78
Oxygenation (%)	85.8	57.8	92.8	103.3	128.7	53.2	91.5
pH	7.8	7.4	8.1	7.8	7.9	7.5	7.8
Alkalinity (mg CaCO dm^{-3})	126	125	135	120	165	180	225
Salinity (PSU)		1.2	1.3	1.1	2.0	2.5	2.9
Conductivity (μS cm^{-1})	1581	2370	2550	2250	3800	4630	5340
Chlorides (mg Cl^- dm^{-3})	333	490	468	481	1020	1520	1390
Sulphates (mg SO_4^{2-} dm^{-3})	112	134	114	97	296	380	412
Potassium (mg K dm^{-3})		8.6	8.6	7.4	10.4	18.4	20
Total hardness (mg CaCO dm^{-3})	251	310	325	315	430	510	505
Calcium (mg Ca dm^{-3})	67	80	75	73	98	112	120
Magnesium (mg Mg dm^{-3})	20.5	26.8	33.5	32.2	45.0	56.0	49.9
Nitrite Nitrogen (mg NO_2–N dm^{-3})		0.10	0.04	0.04	0.02	0.02	0.03
Nitrate Nitrogen (mg NO_3–N dm^{-3})	2.3	1.6	3.0	1.7	0.8	0.4	2.0
Ammonium Nitrogen (mg NH_4–N dm^{-3})	0.29	0.54	0.21	0.37	0.37	0.36	0.29
Phosphate (mg PO_4^{3-} dm^{-3})	0.43	0.47	0.36	0.35	0.47	0.51	0.47
Iron (mg Fe dm^{-3})	0.01	0.34	0.78	0.63	0.13	0.32	0.45
Type of substrate	Sandy and gravel	Sandy with silt	Sandy with silt	Sandy and stones with silt	Empty shells of zebra mussels	Stones with silt	Sandy and stones

collected from the shore zone using a quadrate frame and an Ekman-Birge grab. Additionally, some physiochemical properties of the water were measured in the field and in the laboratory (Tab. 1). All of the molluscs were separated from the sediments, preserved in an 80% ethanol solution, and identified to the species level using the Piechocki and Wawrzyniak-Wydrowska key (2016). The length, height, and width of the shells of *C. fluminea* were measured using a vernier calliper. Small-sized individuals were measured using a stereoscopic microscope equipped with a camera and cellSens Standard 1.4 software.

In total, thirteen mollusc species were identified (seven gastropod species and six bivalve species). Among them, four alien species, *i.e. Corbicula fluminea, Dreissena polymorpha, Physa acuta* and *Potamopyrgus antipodarum,* were found (Tab. 2).

During our study, *C. fluminea* was recorded in the Oder River and in the Gliwice Canal, while it was not observed in the lower course of the Kłodnica River. In 2016, *C. fluminea* was found at two sampling sites in the Oder River, *i.e.* in Dobrzeń Mały (the 162nd km of the river course) and Zdzieszowice (the 108th km of the river course). In 2017, it also occurred in the Oder River in Koźle (the 95th km of the river course) and at one site in the Gliwice Canal (Fig. 1). The new localities are the southernmost records of this species in the Oder River, which indicates that it is still spreading upstream.

A total of 93 individuals of *C. fluminea* were collected. Live individuals were recorded both in the Oder River (66 specimens) and in the Gliwice Canal (3 specimens). Empty shells were only found in the Oder River. The highest number

Table 2. The checklist of molluscs collected in the studied area.

	Oder River				Gliwice Canal		Kłodnica River
	I	II	III	IV	V	VI	VII
Ancylus fluviatilis	−	+	+	−	−	−	−
Bithynia tentaculata	−	+	−	+	+	+	+
Borysthenia naticina	+	−	−	−	−	−	−
*Physa acuta**	−	+	−	−	−	−	−
*Potamopyrgus antipodarum**	+	+	+	+	+	+	+
Radix balthica	−	+	−	−	+	+	−
Viviparus viviparus	+	+	+	−	−	−	−
Anodonta anatina	−	−	−	−	+	−	−
*Corbicula fluminea**	+	+	+	-	+	−	−
*Dreissena polymorpha**	+	+	+	−	+	+	+
Pisidium sp.	−	−	+	+	−	−	−
Sphaerium sp.	+	+	−	−	−	−	−
Unio pictorum	−	−	+	−	−	−	−
Number of taxa	6	9	7	3	6	4	3

+ present; − absent; * alien species.

of live individuals was recorded in the Oder River in Zdzieszowice (38 specimens) in 2017. The density of the live specimens varied from 16 to 118 individuals per m^2.

The shells of the *C. fluminea* that were collected were relatively small. In the Oder River, the mean dimensions of the empty shells were length 15.35 ± 3.98 mm, height 13.53 ± 3.76 mm, and width 10.13 ± 2.67 mm, and the mean dimensions of the live individuals were smaller, *i.e.* length 7.68 ± 5.23 mm, height 6.55 ± 4.66 mm and width 4.54 ± 3.46 mm. In the Gliwice Canal, the mean dimensions of the shells were similar to those in the Oder River: length 8.67 ± 3.06 mm, height 7.50 ± 2.94 mm, and width 5.27 ± 2.04 mm. Our results show that these populations of *C. fluminea* consist of young individuals. This fact is typical for young, growing populations that are in the initial stage of invasion. The dimensions of the shells from the area that was studied are similar to those from other populations of *C. fluminea* in the Oder and Vistula Rivers (Domagała *et al.*, 2004; Wawrzyniak-Wydrowska, 2007; Maćkiewicz, 2013; Bonk *et al.*, 2018), but smaller than those from the heated Konin lakes, which most likely results from the higher water temperature in those lakes compared to the rivers (Urbańska *et al.*, 2018).

In our study, *C. fluminea* was recorded in Dobrzeń Mały and Zdzieszowice in 2016, but one year later, individual specimens were also found in the Gliwice Canal (8.7 km south of Zdzieszowice) and in the Oder River in Koźle (10.1 km south of Zdzieszowice) (Fig. 1). The rate of the spread of *C. fluminea* that has been indicated by different authors varies. Schmidlin and Baur (2007) pointed out that its mean upstream spread in the Rhine River was 2.4 km per year *via* waterfowl and recreational boating. Another study that was carried out in the Rhine River in 1990 suggested that this species spreads at a much higher dispersal rate of 85–115 km per year (Bij de Vaate, 1991).

Our study indicates that *C. fluminea* prefers sandy-muddy sediments. It was recorded on a substrate that consisted of empty zebra mussels only in the Gliwice Canal (Tab. 1). On the other hand, Urbańska *et al.* (2018) noted the highest density of *C. fluminea* on a bottom that was covered with empty zebra mussel shells.

In Poland, *C. fluminea* is considered an alien invasive species which may endanger native species or natural habitats if it is introduced to the natural environment (the regulation of the Minister of Environmental Protection, 2011). It could post a danger especially for other bivalves by rapid growth, competition for food, earlier sexual maturity, a short life span, and high fertility (Sousa *et al.*, 2008). Nevertheless, in small densities, it does not have to be seen as a threat for native species, but it requires monitoring as do all invasive species do (Sousa *et al.*, 2008; Ilarri *et al.*, 2014).

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